Lepidoptera

Weyerhaeuser Company
Research and Development — Forestry and Timber Products

REPORT NO. 1303
050-3112/1

IMPACT OF WESTERN PINE SHOOT BORER ON THE GROWTH OF PONDEROSA PINE PLANTATIONS

Ronald L. Heninger
Klamath Falls Forestry Research Field Station, Klamath Falls, Oregon 97601

TECHNICAL SUMMARY

Western pine shoot borer (*Eucosma sonomana* Kearfott) is an important pest of ponderosa pine (*Pinus ponderosa* Laws.). Larval mining of the terminal shoot has caused losses in annual height growth which would reduce the total volume produced by the stand. This project was designed to assess the potential growth loss caused by *Eucosma* by developing a case history for four older plantations.

The impact of *Eucosma* on height growth and volume loss was not as large as was anticipated. The reduction in mean annual height growth rate due to *Eucosma* infestation was 3.8 cm/year (1.5 in/year), or 8.2%. There was no consistent carryover effect to next year's growth. Volume loss ranged from 0 to 29 m^3/ha (0 to 420 ft^3/A) for plantations 40 to 49 years old. Estimated volume losses at a rotation of 60 years ranged from 0 to 50 m^3/ha (0 to 710 ft^3/A) or up to 11% of the total "hypothetical" uninfested volume.

Eucosma generally started to infest trees when they reached 1.4 m in height. Infestation seemed to increase over time at a rate of 0.6 to 1.5% per year of plantation age after reaching 1.4 m. At young ages, up to 15 years, *Eucosma* seemed to show a preference for taller trees, however this relationship disappeared as the average height of the stand reaches 3.6 m (12 ft.). There seems to be a strong pattern between *Eucosma* infestation and forking, but not a cause and effect relationship. *Eucosma*-caused forks represented only 3% of the internodes evaluated.

HYF SIGNIFICANCE

An effective pheromone control method has been developed. Information on the potential volume loss due to *Eucosma* is essential in evaluating the cost-benefit of pheromone applications. By evaluating annual height growth losses and determining infestation level and knowing the site index, candidate stands could be priorized for pheromone treatments.

Eastern Oregon Forest Management
050-3112/1

AUTHOR'S SIGNATURE	DATE	
Ronald L. Heninger	12/11/81	
AUTHOR'S NAME (Typed)	APPROVED BY (Signature)	DATE
Ron Heninger	H Ballard.	12/16/

Strictly Proprietary (Red): Disclosure strictly limited to persons on a managed list. Contact ______

Proprietary (Yellow): Disclosure limited to persons confidentially bound to Weyerhaeuser on a need to know basis.

X Non-proprietary (Green): Disclosure unlimited.

IMPACT OF WESTERN PINE SHOOT BORER ON THE GROWTH OF PONDEROSA PINE PLANATATIONS

Ronald L. Heninger
Klamath Falls Forestry Research Field Station, Klamath Falls, Oregon 97601

INTRODUCTION

This study was a cooperative effort between the U.S. Forest Service Pacific Southwest Forest and Range Experiment Station, Berkeley, California and Weyerhaeuser Company's Forestry R&D Division, Klamath Falls Forestry Research Field Station. T.W. Koerber, Research Entomologist with the PSW Station, assisted by reviewing the research plan, evaluating *Eucosma* infestations in the field and reviewing the analysis results and report.

Western pine shoot borer (*Eucosma sonomana* Kearfott) is an important pest of ponderosa pine (*Pinus ponderosa* Laws.). The adult moths start emerging from the soil during the first and second weeks of April (Overhulser 1977a and b). They continue to emerge and the flight period lasts seven to nine weeks ending approximately the first week of June. The female moth lays eggs under the bud scales of the terminal shoot between mid-April and June. The larva will immediately enter the pith region of the elongating shoot where they feed for several weeks. Generally there is only one insect per shoot and feeding damage is confined to the pith region; the xylem and phloem are not involved. The larva develop through five instars and reach maturity between the first week and end of July. The mature larva chews an exit hole in the side of the infested shoot and drops to the ground. There it spins a cocoon at the soil-duff interface where it remains in the pupal stage until the next April or May.

This larval mining of the terminal shoot has caused a loss in annual height increment ranging from 18 to 28 percent of the uninfested growth rate in young trees (Stoszek 1973, Overhulser 1979a and Luther 1980). This reduced height growth would reduce the total volume produced by the stand.

Key Words: ponderosa pine plantations, *Eucosma sonomana*, western pine shoot borer, growth impact, height growth

Eastern Oregon Forest Management
050-3112/ 1

An effective control method for Eucosma has been developed (Overhulser 1979b, Sower et al 1979, Overhulser et al 1980 and Sartwell et al 1980), and two registered formulations are commercially available. A pheromone sex attractant disrupts the mating of Eucosma thus reducing the number of mated females. This has greatly reduced the incidence of attack and thereby reduced height growth losses. However, neither the question of what are the potential volume gains derived from pheromone application or where phermone applications will be most cost-effective have not been addressed. This study was designed to assess the potential growth loss caused by Eucosma in selected plantations.

METHODS

Seven ponderosa pine plantations, all over 30 years of age and located in National Forests, were field surveyed to evaluate their history of Eucosma attack. From these, four plantations were selected for intensive sampling, Figure 1. A case history of shoot borer infestation over time was developed for each plantation by felling trees, measuring their annual and cumulative height growth and determing the presence or absence of Eucosma.

At each plantation two randomly located 0.0625 ha (0.15 A) temporary plots were established to provide stand structure information. Diameters were measured to the nearest 1.0 mm and crown class estimated for each tree.

Fifty sample trees at each plantation were randomly selected from an approximate area of 1 ha for felling, annual height growth measurements and Eucosma evaluations. The diameters and crown classes of these trees were measured to determine if the sample trees were representative of the plantation population as represented in the temporary plots. Accumulated frequency as a percent was plotted over diameter for the two plots and the 50 sample trees and a Kolmogonov-Smirnof test was conducted to determine if the two sample populations were different. In all cases they were not significantly different at the 95% level. Sample trees were rejected if mechanical damage or severe forking caused by porcupines were found.

The 50 samples trees were then felled and limbed leaving 20 cm branch stubs to aid in forking determination. A spray paint mark was made beneath each internode on the sample tree. The number of height segments above breast height (BH) was checked against BH age (ring count) to ensure all internodes were identified. Total accumulated height, referenced to BH age, from the ground up was measured to the nearest 0.01 m. Below breast height, height measurements were made to all visible nodes. In most cases all segments could not be found below breast height; therefore, breast height was used as a standard reference point.

The trees were sectioned 10 cm below each internode. Previous work by Koerber, and also Overhulser (1977b) indicated that this distance below the node was adequate to determine the presence or absence of Eucosma infestation (average Eucosma mine length was 17.4 ±5.5 cm). The pith of each section was examined for indications of Eucosma. The pitch impreganated damaged segments of the pith remain visible through the life of the tree. Uninfested internodes (U)

were coded "0" and infested internodes (I) coded "1". All stem deformities such as forking were also recorded using the following codes:

2 - fork with both old and new terminals uninfested
3 - fork with old terminal uninfested and new terminal infested
4 - fork with old terminal infested and new terminal uninfested
5 - fork with both old and new terminals infested

All data were recorded by calendar year and tree age.

The analysis procedure evaluated height increment through a non-linear regression approach. The regression technique estimated an exponential and a linear height growth phase for each tree similar to those described by Namkoong and Conkel (1976). The individual tree data were separated into four groups: (1) the first set contained all data for each tree - 'U' and 'I' values including forks; (2) the second contained only height increments that had no Eucosma infestation - 'U' values only and no forks; (3) and a third included only height increments with two consecutive years with no Eucosma infestation - 'UU' values only, no forks; and (4) finally a set containing all height increments which were infested by Eucosma - 'I' values only, no forks. The regression technique was run against each of these sets of data.

For each data grouping, the linear coefficient (mean annual height increment) for each tree was multiplied by the number of years in the linear growth phase and added to the height attained during the exponential growth phase to estimated total tree height. These height estimates were then used with the tree's current diameter to calculate the tree's volume. It was assumed that Eucosma does not affect diameter growth.

To determine if there was a carryover effect or lag recovery time for height growth when an uninfested segment grew from an infested segment, the mean growth rate by crown class in the linear phase was evaluated for four condition:

Infestation Category	Definition
UU	Uninfested growing from previously uninfested terminal
UI	Unifested growing from previusly infested terminal
IU	Infested growing from previusly uninfested terminal
II	Infested growing from previously infested terminal

If the UI mean growth rate, by crown class, equalled the UU mean growth rate, there was no lag or carryover effect. This also equalled the uninfested mean height growth rate. If a carryover effect was detected, UI significantly less than UU, the procedure to estimate heights was conducted on the data set with uninfested height increments following an infested increment deleted. The mean values for IU and II equalled the mean height growth rate of Eucosma infested segments.

To calculate the volume loss/hectare, these procedures were followed. The measured total heights and diameters of the felled sample tree were used to calculate the height-diameter coefficient with the following equation:

height = A**EXP (B*DBH**C) + 1.3

The A, B and C coefficients were then applied to the temporary plot measured diameters and heights estimated for each tree. These height estimates were equivalent to heights with current Eucosma infestation levels. This procedure was then repeated with the heights estimated from uninfested height increments. This resulted in a new height estimated for each tree in the temporary plots equivalent to a "hypothetical" uninfested condition. These two height estimates for each tree were then used to calculate volume for each tree using its current diamter. The volume equation was:

volume = EXP(-7.8589 + 1.85293*lnx(DBH) + 1.4189*lnx(HT) + 15.64209/HT)[1]

The sum of volumes were adjusted by plot size to estimate volumes/hectare. The differences between the two volume estimates are considered to be due to Eucosma infestation.

PLANTATION INFORMATION

The average stand statistics for the four plantations are shown in Table 1. The seed sources were unknown for all plantations. The Bowen Creek plantation is located on the Butte Falls Ranger District of the Rogue River National Forest (NW¼, S29, T35S, R3E). The stand received a precommercial thinning in the fall of 1969 removing mostly porcupine damaged trees. The Sugar Hill (S½, NW¼, S5, T45N, R15E) and Planting Camp (NW¼, SW¼, S13, T46N, R14E) plantations are both located on the Warner Mountain Ranger District of the Modoc National Forest. The Sugar Hill plantation received a precommercial thinning somewhere between 10 and 15 years ago, the exact date is unknown. Planting Camp received a very light sanitation thinning in the spring of 1980 removing porcupine damaged trees. The K.C. Reservoir plantation (SE¼, NW¼, S23, T40N, R4W) is located on the Mount Shasta District of the Shasta-Trininty National Forest. Planted on the southwestern slope of Mt. Shasta, the plantation experienced brush competition for approximately 15 to 17 years limiting height growth until the trees average 4 m in height when they essentially became free to grow.

RESULTS AND DISCUSSION

Infestation Over Time

Eucosma started to infest these plantations when the dominant trees averaged 1.4 m in height. This height relationship with Eucosma infestation is consistent with today's current plantation experience on the Klamath Tree Farm.

[1] Bower, et al, 1978. Proprietary.

Generally, infestations seemed to increase up to a point and then level off or increase slightly over time, Figure 2. To calculate the relationship between percent infestation and time, a linear regression (% infestation = $b_o + b_1$ {plantation age}) was developed. The regression analysis started with the first year in which infestation occurred and its corresponding age from Figure 2. The mean slope (b_1) was 1.03 and ranged from 0.64 at Sugar Hill to 1.55 at Bowen Creek (Appendix Table 1). This means, that on the average, infestation rate increased 1.03 percent per year. All regressions had a significant F-ratio at the 0.05 level. The average infestation rate was reached when the average stand height was 3.6 m (12 ft.). Once these heights were attained, the same regression procedure was calculated. The average slope was 0.64 or an increase in infestation rate of 0.64 percent per year after reaching 3.6 m average height. All regressions, except Sugar Hill, were significant. The frequency of infestations never increased to a point where all the trees were being attacked in any year. This result was inconsistent with previous observations by Figueroa (1976), which showed increasing infestation rate of 3.07 percent per year for a 26-year old plantation with a mean height of 6.0 m (19.7 ft).

It is interesting to note that Bowen Creek was precommercially thinned in the fall of 1969 and the infestation level fell off following the thinning. This was not expected because thinning reduces the number of trees present without reducing the number of Eucosma pupae present on the ground, therefore it was assumed that there would be an increase in infestation level.

Infestation and Total Tree Height

Literature and our previous observations (Daniels 1974) indicated that the taller trees experienced the higher Eucosma infestation rate. The stand discussed had attained an average height of only 5.6 m (18 ft). Average total height for this study ranged from 11 to 14 m (36 to 46 ft) and the relationship of infestation rate to height covers a much broader range. To calculate the relationship between height and infestation, a linear regression (percent infestation above BH to top = $b_o + b_1$ {total height}) was developed at each of three ages; 15, 27 and total age for all plantations, Figure 3, Appendix Table 2. The results indicate an increasing infestation rate with increasing height for the 15-year data, with an average upper height of 5 m and slope of 3.57. This compares to Daniels' slope of 3.11 for the same height range. During the mid ages of plantation development, age 27, the relationship decreased with an average slope of 1.96. At total age, the relationship almost disappeared with an average slope of 0.87. When all three age groups were pooled to detect the relationship over the total height history of the stand, the average slope was 1.49 thus indicating that infestation rate increased by 1.49 percent per meter of height growth above breast height. Some regressions were significant, however the r^2 values were low and the standard errors of the estimates usually were wider than the minimum and maximum points of the regression lines. The relationship is very poor except possibly during the early part of stand development up to age 15. Based on these results one cannot say that the tallest trees will have the highest percent infestation. The predictability of this relationship is extremely variable with large confidence limits. However, one can surmise that all trees are susceptible to Eucosma attack regardless of their height after reaching some minimum height.

Forking

Forking is caused when the terminal is replaced by an upturned lateral branch and this lateral retains dominance over the old terminal. Stevens and Jennings (1977) indicate that Eucosma can cause forking. In this study, the percentage of internodes above breast height that were forked ranged from 2 to 12%, Table 2.

The data were summarized as described in Methods for eight general groups, including the year previous to the fork: U(2) U(3), U(4), U(5), I(2), I(3), I(4) and I(5). Of these groups, two can be considered as non-Eucosma caused: U(2) and U(3) and the rest could possibly have been caused by Eucosma. Forks potentially caused by Eucosma ranged from 69% of the recorded forks at Bowen to 37% at Planting Camp or 8% to 1% of the total internodes in the linear growth phase above breast height. There seems to be a pattern between Eucosma infestation and forking, but not a cause and effect relationship.

Forking, whether Eucosma caused or not, affects height growth increment. The lateral extension is nearly always shorter than terminal growth, thus reducing potential height growth when it does become vertical and dominant. In these plantations height growth reductions caused by forking range from 10.5 to 28.1% of the average UU height growth potential.

In summarizing the data there were several trees which seemed to have a high propensity for forking, whether Eucosma caused or not. For example, at Bowen Creek five trees contained a total of 45 forks or 29% of the total forks. Forking is a inheritable trait and these five trees showed an extremely high rate of forking for which the majority were 2s and 3s, using the Eucosma code, (see Methods).

Mean Height Increments

Mean height increments by crown class were summarized for four internode categories: UU, UI, IU and II. This was necessary before building a "hypothetical" uninfested tree because it has been reported that there is a carryover effect from the preceding year's infestation (Luther, 1980 and Stoszek, 1973). If this were ture, adjustments would have to be made in the data base used to develop a "hypothetical" uninfested tree. The procedure was to use all height increments in the linear height growth phase and summarized by the four groups above by crown class. The results were not consistent, Figure 4. At Bowen Creek, the dominant and suppressed trees showed a significant carryover effect (UI vs. UU). The suppressed group contained only five trees and due to their crown position and knowing that many other factors affect height growth of suppressed trees, the author does not believe the differences in the suppressed group were caused by Eucosma. There were no significant differences between the UU and UI categories for the codominats or intermediate crown classes. At Sugar Hill the codominats showed a carryover effect as did the intermediate and suppressed crown classes at K.C. There was no carryover effect at Planting Camp. Because there was no consistency in the carryover effect, it cannot be considered to affect all trees and sites in the same manner.

This procedure also allows one to evaluate the effect of Eucosma on annual height growth by crown class, Figure 4 and Appendix Table 3. Mean height growth for Eucosma infested internodes compared to the UU internodes ranged from a +18.8% to a -16.6%. Thus, infested internodes did not always show a reduction in height growth. The average weighted percentage in height growth loss ranges from +13.7% to -10.8%, Table 3. The weighted average annual loss in height growth expressed as a percent was -8.2 (excluding Planting Camp). This value is much less than that reported in the literature.

The absolute loss in centimeters per year is a better measure of the effect of Eucosma on height growth. The weighted mean loss in annual height growth is shown in Table 4. Planting Camp is an anomalie as we really don't expect infestations of Eucosma to show increased tree growth. Figure 5 illustrates the average annual height growth data for all sites with the standard deviations plotted. The variation around each mean is quite learge. Even though there are significant differences at Planting Camp from the UUs, it is questionable whether these differences are really meaningful.

The weighted average loss in annual height growth, excluding Planting Camp, was 3.8 cm/year of infestation (1.5 in/year). The average is based on 1,295 internodes in the UU category and 1,425 internodes in the IU and II categories. Table 4 also includes some previously reported losses in annual height growth. The losses at Bowen Creek are presented for three time periods: 20, 30, 40 years. The reduction in height growth due to Eucosma is greater in the younger age classes which seems to be consistent with other plantations, except Planting Camp. These losses are not too dissimiliar from those reported by Stoszek (1973) and Luther (1980) for the same age period. If this characteristic is consistent we can overestimate the impact of Eucosma on volume in young plantations because of the greater losses incurred during the first 10 to 20 years. The reductions in height increments seem to decrease with plantation age, although the incidence of infestation remains high.

Derivation of "Hypothetical" Uninfested Tree

Annual height increments for each tree were fit to the non-linear regression technique described in the Methods section, top of Figures 6a and 6b. The procedure worked very well as shown in the height over age graphs using actual and calculated heights, Figure 7. The mean residuals (estimated minus actual height) by plantation and crown class are listed in Appendix 4. All estimates were within 1% of actual height; therefore, a very accurate method to predict tree heights. This is an important factor because the "hypothetical" uninfested tree height is modeled by the same procedure. The residuals are very small and range from -0.01 m to +0.19 m. This procedure generally overestimates total height; however, the overestimates are very small as shown in the bottom of Appendix 4 which incorporates all 200 felled trees. The overestimates of the mean residuals and total heights were from 3 to 7 cm (1.2 to 2.8 in) which is within the error of measurement. Based on the fact that the estimated heights equal actual height, it is assumed that the "hypothetical" uninfested height would be estimated with the same precision.

The "hypothetical" tree model illustrated in the middle of Figures 6a and 6b was used to calculate total height of the uninfested tree. The uninfested

height increments illustrated in the middle of Figure 6a are for a dominant tree at Bowen Creek. The dominant crown class showed a significant carryover effect, therefore only the UU values were used to calculate the uninfested height growth rate. The condominant trees had no carryover effect, thus all "U" values were used in the model to calculate average annual uninfested height growth, Figure 6b, middle. The linear coefficient for the uninfested height increments (excluding all forks) was multiplied by the number of years in the linear phase and height added to the height attained during the exponential phase. The difference between the two heights -"hypothetical" uninfested minus estimated current height - was the loss attributed to Eucosma, bottom Figures 6a and 6b.

This carryover effect, although important from a biological point of view, did not make a significant difference in the total volume produced by the stand. For example, at Sugar Hill the codominants showed a significant carryover effect. By adjusting for this in the height model by deleting all UI internodes, as shown in Figure 6a (middle), the mean total height was increased only 0.56 m (1.8 ft) or 4.4 percent of the total height estimated by using all 'U' values. This resulted in only 0.01 m^3 per tree (0.38 ft^3 per tree) increase in volume. When adjusted up to a hectare basis, it resulted in only a 0.7 m^3/ha (10 ft^3/A) or 0.7 percent increase in total volume as compared to using the volume estimated by using all 'U' values without adjusting for the carryover effect. Therefore, the carryover effect is negligible with respect to the total volume produced by the stand.

There are a couple of other important points illustrated in Figures 6a and 6b. For example, in Figure 6a (top) the longest and shortest increments were uninfested. If it was assumed that short increments were infested because Eucosma reduces height increment, one would have incorrectly assessed this internode. On the other hand, Figure 6b (top) the longest and shortest increments were infested with Eucosma. Again, it could be assumed that the longest increment of a tree would not have a Eucosma infestation. It is also evident that about one-half of the infested increments are above the mean height increment value and one-half are below. This illustrates the importance of destructive sampling to evaluate the presence or absence of Eucosma infestation. The piths of each increment must be examined to accurately assess the impact of Eucosma on growth.

The above examples in which longer than average height increments were found to be infested, may be explained by understanding the flight and egg laying cycle, and feeding habit of Eucosma in relation to the growth period of the tree. As noted, Eucosma start emerging from the soil and mating in mid-April and continue until June. In the Eastern Oregon Region, terminal buds of ponderosa pine generally start to swell and elongate the first week of May and total elongation is completed by mid-July. The oviposition period of the female moth extends from mid-April until June, therefore it is conceivable that some of the larva could start mining a terminal that has completed 50 to 70 percent of its elongation. Thus, the impact of Eucosma would be minimal or non-existent as compared to a terminal that had larval mining starting before significant bud elongation. We do not understand the interaction of larva boring into the bud and bud physiology. This relationship really needs to be defined more thoroughly before an accurate determination of Eucosma impact can be made.

Another fact illustrated is that the shortest increments for both trees illustrated in Figure 6 occurred during the same year, 1960. Approximately one-half of the trees at Bowen Creek also displayed a short height increment in 1960. Both uninfested and infested increments grew about 20 cm (8 in). This was further illustrated at the K.C. and Planting Camp plantations where the increments for almost all trees during 1977 and 1978 were very short resulting from the winter drought of 1976. The height increments for these years were very similar; uninfested was 25 and 21 cm/yr (9.8 and 8.3 in/yr), respectively for K.C. and Planting Camp compared to infested increments of 29 and 20 cm/yr (11.4 and 7.9 in/yr), respectively. Thus it seems that drought, which is known to reduce growth, can mask the effect of Eucosma on height growth increment, and that it has a stronger influence on growth than Eucosma. The Sugar Hill plantation did not show the effect of drought on height increment. This may be because it carried less than one-half as many stems per hectare and moisture was not limited because there were fewer trees using available water. Eucosma may only become an important factor when other environmental factors are not limiting growth.

Mean height impact is summarized in Table 5. Height losses range from 0.0 to 1.4 m (0 to 4.6 ft) for the particular age of each plantation. The percent loss in total height does not differ greatly from the weighted percent losses based on mean annual height increments discussed above.

The two heights for each tree (uninfested and infested) and its corresponding diameter were fit to the height-diameter model and coefficients applied to the diameters of the plot trees. This results in two height estimates for each tree. The data were then used to develop stand statistics of basal area, volume, mean diameter, etc. Total volume impact is summarized in Table 6. Current stand volumes ranged from 101 to 260 m^3/ha (1,948 to 3,716 ft^3/A). The differences between the "hypothetical" uninfested volume and current volume is shown in the volume loss column. Eucosma caused a loss of volume ranging from 0 to 29 (±7) m^3/ha (0 to 420 ft^3/A) or 0 to 10% decrease in the potential uninfested volume. These losses are for current age of the plantations.

One of the driving questions behind this project was how much volume loss could be expected at rotation age. To estimate the volume loss at a rotation of 60 years for each sample plantation, the following procedure was used. It was assumed that infestation level would remain the same and therefore mean infested height growth would remain proportional to the mean height growth from the yield tables which inherently have shoot borer effects built into them. The current stand parameters for each plantation (site index, age, mean diameter, mean infested height and stocking) were matched up to a ponderosa plantation yield table (WeyCo, 1980 unpublished). Mean diameter growth from the yield tables between current plantation age and 60 years was added to the mean current diameter of the plantation, thus continuing with the assumption that diameter is unaffected by Eucomsa infestation. Mean plantation infested and "hypothetical" uninfested 60-year height was extrapolated proportionally from the yield table heights for current plantation age and age 60 with current plantation heights. From these mean tree values (DBH and heights), the volume equation was used to determine the volume per tree which was multiplied by stocking. Stocking was adjusted for the same mortality accounted for in the yield tables. This then resulted in an estimate of volume per hectare for the

infested and the "hypothetical" uninfested plantation (Table 7). There is some danger in extrapolating by use of proportional height growth; however, the graphed results of the extrapolated infested and uninfested height curves look reasonable. The results indicate that Bowen Creek would lose approximately 50 m^3/ha (710 ft^3/A) or 11% of the total "hypothetical" volume. Sugar Hill and K.C. would lose approximately 12 and 11 m^3/ha (170 and 150 ft^3/A) or 5 and 4% of the total uninfested volume. Planting Camp volumes were virtually the same for both infested and uninfested.

There is no other published data with 40 years of growth available for comparisons. However, Luther's thesis (1980) contains enough information that an extrapolation to rotation age can be made. In order to calculate volume loss with these data, it was assumed that infestation rate would remain constant at the highest reported level of 70 percent and a lower level of 40 percent, that the stands had an average site index of 20 m (65 ft) with average diameter, height and stocking equal to Weyerhaeuser Company unmanaged plantation yield tables with 1,600 planted trees per hectare (650 trees/A) and a 60-year rotation. With the worst case, losing 6.1 cm per year (2.4 in/yr) per infestation, total volume loss was estimated at 54.2 m^3/ha (770 ft^3/A) or 15 percent of total volume. Using the lowest annual height loss per infestation, 2.5 cm per year (1.0 in/yr), total volume loss was 22.9 m^3/ha (330 ft^3/A) or 6 percent of total volume. If 40 percent infestation were used, for example, the estimated volume losses at rotation were 31.4 m^3/ha (450 ft^3/A) and 12.9 m^3/ha (180 ft^3/A) for the worst and low cases of height reductions. These values are not out of line with the estimated losses at rotation for the plantations used in this project (Table 7).

CONCLUSIONS

The impact of *Eucosma* on height growth and volume loss was not as large as was anticipated. I think this is best explained by the fact that older plantations were sampled and destructive sampling was used to determine the presence or absence of *Eucosma* terminal mining. The impact of *Eucosma* is buffered as the plantation matures. Our previous experience has been with younger plantations where the reductions in height growth are larger and *Eucosma* infestations were based on foliage configuration rather than actual examination of the pith region. Extrapolations from these young stands tend to overestimate the long-term impacts.

Eucosma infestation over time seemed to increase over time until the insect reaches a limiting level. During the young ages *Eucosma* seemed to show a preference for taller trees. However, this relationship disappears as the average height of the stand reaches 3.6 m (12 ft). Thus past this average height, all trees, regardless of their crown position, had an equal chance to become infested with *Eucosma*. The average increase in infestation rate after 3.6 m height was 0.64 percent per year. The population dynamics of the insect and the individual stand characteristics combine to create different maximum levels for each stand.

Eucosma generally started to attack trees once they reached 1.4 m (4.5 ft) in height or breast height. The lowest height that *Eucosma* was found present was at 0.8 m (2.6 ft). Infestation rates started to increase when the majority of

the trees were 1.4 m or taller. This finding is consistent with the literature and current examples of young plantations on Weyerhaeuser land.

The reduction in the weighted mean annual height growth rate due to Eucosma infestation (excluding Planting Camp) was 3.8 cm/year (1.5 in/year) or 8.2%. There were no consistent trends in the carryover effect when an uninfested node is growing from an infested node. The one generalization that can be made for the carryover effect is that it probably makes little difference in the total volume produced by the stand.

In this study it was found that forking represents a very small proportion of the internodes, averaging only 5%. There seems to be a strong pattern between Eucosma and forking, but not a cause and effect relationship. Eucosma caused forks were only 3% of the segments evaluated. However, forks do cause a significant reduction in annual height growth whether Eucosma caused or not.

The non-linear regression technique estimating an exponential and linear growth rate worked very well. The procedure generally overestimated total height; however, the overestimate is very small ranging from 3 to 7 cm (1.2 to 2.8 in) which is within the error of measurement. This is an important factor because the "hypothetical" uninfested tree height is modeled by the same procedure. Based on the fact that the estimated heights equal actual heights, it is assumed that the "hypothetical" uninfested height would be estimated with the same precision.

The volume differences between the "hypothetical" trees and the current Eucosma infested trees ranged from no difference to 29 m^3/ha (420 ft^3/A) for current plantation age. These volume losses are very close to the estimated volume loss just using the 50 sample trees and proportioning it to the population of the temporary plots. On a 60-year rotation the potential volume losses ranged from 0 to 50 m^3/ha (0 to 710 ft^3/A) or up to 11% of the total "hypothetical" volume. These values represent the maximum loss to Eucosma because all forks were eliminated from the model, and it is known that if natural forks were left in the data set the volume loss would be slightly less.

Based on these results, there may be some plantations where the volume losses are high enough to be concerned about. On the other hand, there are plantations where Eucosma infestations result in negligible losses. This indicates that we still have much to learn, particularly in developing a method to identify those plantations or sites that have a high risk for volume loss.

REFERENCES

Bower, D. R., P. F. Figueroa and L. Spencer. 1978. Total and merchantable cubic-foot volume equations and tables for ponderosa pine at the Klamath Tree Farm. Weyerhaeuser For. Res. Tech. Rep. 042-1401/78/57. Proprietary.

Daniels, T. G. 1974. Relationship of shoot borer attacks to tree size in pine plantations. Pres. made N.W. Science Conf. 1974. (Abstract.)

Figueroa, P. F. 1976. 1975 shoot borer assessment at Grubb Springs. Memo 1/11/76 to R. L. Heninger.

Namkoong, G., and M. T. Conkle. 1976. Time trends in genetic control of height growth in ponderosa pine. For. Sci. 22:2-12.

Luther, S. C. 1980. Western pine shoot borer infestation levels in ponderosa pine associated with site conditions. MS Thesis, Univ. of Idaho Grad. Sch., Moscow, 50 p.

Overhulser, D. L. 1977a. Flight and ovipositional activity of Eucosma sonomana in the Klamath Falls Region. Weyerhaeuser For. Res. Tech. Rept. 042-4204/77/66.

Overhulser, D. L. 1977b. Notes on the life history and breeding sites of Eucosma sonomana at Klamath Falls. Weyerhaeuser For. Res. Tech. Rept. 042-4204/77/67.

Overhulser, D. L. 1979a. Eucosma impact studies. Memo 2/13/79 to J. A. Rochelle.

Overhulser, D. L. 1979b Control of Eucosma sonomana (Lepidoptera: Tortricidae, Olesthreutidae) with aerially applies hollow fibers containing synthetic sex attractants. Weyerhaeuser For. Res. Tech. Rep. No. 042-4204/79/54.

Overhulser, D. L., G. E. Daterman, L. L. Sower, C. Sartwell and T. W. Koerber. 1980. Mating disruption with synthetic sex attractants controls damage by Eucosma sonomana (Lepidaptera: Tortricidae, Olethreutidae) in Pinus ponderosa plantations. II. Aerially applied hollow-fiber formulation. Can. Ent. 112(2):163-165.

Powers, R. F. and W. W. Oliver. 1978. Site classification of ponderosa pine stands under stocking control in California. Res. Paper PSW-128, 9 p. Pacific Southwest For. & Range Expt. Stan., For. Serv., U.S.D.A. Berkeley, Calif.

Sartwell, C., G. E. Daterman, L. L. Sower, D. L. Overhulser and T. W. Koerber. 1980. Mating disruption with synthetic sex attractants control damage by Eucosma sonomana (Lepidaptera: Tortricidae, Olethreutidae) in Pinus ponderosa plantations. I. Manually applied polyvingyl chloride formulation. Can. Ent. 112(2):159-162.

Sower, L. L., G. E. Daterman, C. Sartwell and H. T. Cory. 1979. Attractants for the western pine shoot borer, Eucosma sonomana, and Rhyacionia zozana as determined by field screening. Environ. Entomol. 8:265-7.

Stevens, R. E. and D. T. Jennings. 1977. Western pine shoot borer: A threat to intensive management of ponderosa pine in the Rocky Mountain area and the Southwest. Gen. Tech. Rep. RM-45. Rocky Mtn. For. & Range Expt. St., For. Serv., U.S.D.A., Fort Collins, Co.

Stoszek, K. J. 1973. Damage to ponderosa pine plantations by the western pine shoot borer. J. For. 71:701-705.

Table 1. Average stand parameters for shoot borer growth impact project.

	Elevation	Age	Site Index[1/]		Diameter		Stocking		Basal Area		Total Volume		Eucosma Infestation[2/]
	m	yrs	m	ft	mm	in	t/ha	t/A	m^2/ha	ft^2/A	m^3/ha	ft^3/A	%
Bowen Creek	850	40	24	(78)	240	(9.5)	1 048	(424)	46.5	(203)	260.0	(3 716)	48
Sugar Hill	1 740	40	21	(66)	273	(10.7)	381	(154)	22.3	(97)	100.6	(1 438)	40
K.C.	1 230	42	21	(69)	216	(8.5)	816	(330)	29.9	(130)	136.3	(1 948)	16
Planting Camp	1 780	49	16	(54)	270	(10.6)	832	(337)	47.6	(207)	217.1	(3 102)	23

1/ Site index determined by use of Powers and Oliver (1978) method; height at 50 years plantation age.

2/ Percentage equals number of Eucosma attacks divided by breast height age.

Table 2. Forking summary for shoot borer growth impact project.

Plantation	Total Number Forks	Percent of Total Internodes[1/]	Non-*Eucosma* Caused	*Eucosma* Caused	Mean Height Growth	Height Growth Reduction[2/]
		%	%	%	cm/yr	%
Bowen Creek	156	11.9	3.7	8.2	37.9	20.4
Sugar Hill	31	2.2	0.8	1.4	28.9	28.1
K.C.	24	2.8	1.6	1.2	32.2	21.4
Planting Camp	51	3.0	1.9	1.1	26.4	10.6

1/ Total internodes from linear growth phase only.

2/ Height growth reduction as a function of uninfested annual height growth rate.

Table 3. Loss in mean weighted annual height growth as a percent of uninfested growth rate.

Plantation	Mean Weighted Loss in Annual Height Growth	No. Observations Uninfested	Infested
	%	UU	IU & II
Bowen Creek	-10.75	315	625
Sugar Hill	- 6.57	489	596
K.C.	- 5.31	491	204
Planting Camp	+13.72	1,021	417
		2,316	1,842

Average weighted loss in annual height growth = -3.3%

-Minus Planting Camp = -8.2%

Table 4. Weighted mean loss in annual height growth per infested year with literature comparisons.

Plantation	Age	Weighted Mean Loss in Annual Height Growth	
	yrs	cm/yr	in/yr
Bowen Creek	20	-7.1	(-2.8)
	30	-4.3	(-1.7)
	40	-5.4	(-2.1)
Sugar Hill	40	-2.6	(-1.0)
K.C.	42	-2.2	(-0.9)
Planting Camp	49	+4.0	(+1.6)

Annual weighted loss in height growth = -2.0 cm/yr (-0.8 in/yr)
- excluding Planting Camp = -3.8 cm/yr (-1.5 in/yr)

S.E. Oregon[1/]	15	-7.4	(-2.9)
Idaho[2/]	7 - 19	-4.2	(-1.6)

[1/] Stoszek, 1973.

[2/] Luther, 1980.

Table 5. Mean height summary developed from temporary plots.

Plantation	Age	Infestation	Estimated Current Height		Estimated Hypothetical Height		Height Loss		
	yrs	%	m	(ft)	m	(ft)	m	(ft)	%
Bowen Creek	40	48	14.4	(47)	15.8	(52)	1.4	(4.6)	8.8
Sugar Hill	40	40	12.6	(41)	13.2	(43)	0.6	(2.0)	4.6
K.C.	42	16	10.7	(35)	11.1	(36)	0.4	(1.4)	3.6
Planting Camp	49	23	12.9	(42)	12.8	(42)	+0.1	(+0.3)	+0.8

Table 6. Volume summary developed from temporary plots.

Plantation	Age	Infestation	Estimated Current Volume		Estimated Hypothetical Volume		Volume Loss			
	yrs	%	m^3/ha	ft^3/A	m^3/ha	ft^3/A	m^3/ha	(SE)	ft^3/A	%
Bowen Creek	40	48	260	(3 716)	289	(4 136)	29	(7)	(420)	10
Sugar Hill	40	40	101	(1 438)	106	(1 510)	5	(1)	(72)	5
K.C.	42	16	136	(1 948)	140	(1 998)	4	(1)	(50)	3
Planting Camp	49	23	217	(3 102)	216	(3 087)	- 1	(1)	(-15)	0

Table 7. Estimated volume for unmanaged plantations at 60-year rotation.

Plantation	Mean Diameter		Hypothetical Mean Height		Infested Volume		Hypothetical Volume		Volume Loss		Percent of Total
	cm	in	m	ft	m^3/ha	CCF/A	m^3/ha	CCF/A	m^3/ha	CCF/A	%
Bowen Creek	31	(12.4)	22	(73)	423	(60.5)	473	(67.6)	50	(7.1)	11
Sugar Hill	34	(13.5)	19	(62)	199	(28.4)	211	(30.1)	12	(1.7)	5
K.C.	27	(10.8)	16	(52)	235	(33.6)	246	(35.1)	11	(1.5)	4
Planting Camp	30	(11.9)	15	(51)	304	(43.4)	302	(43.1)	+ 2	(+0.3)	0

FIGURE 1. VICINITY MAP OF PLANTATIONS SAMPLED FOR SHOOT BORER GROWTH IMPACT PROJECT.

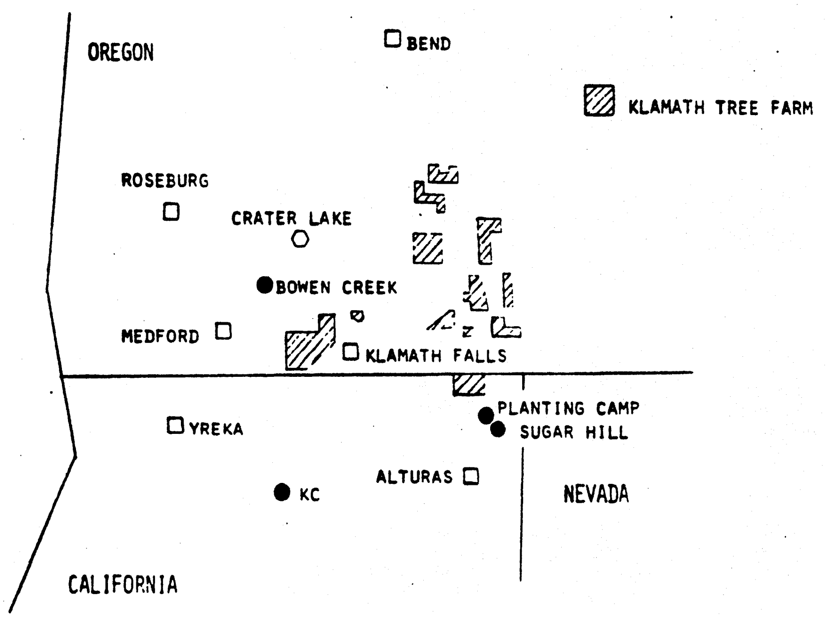
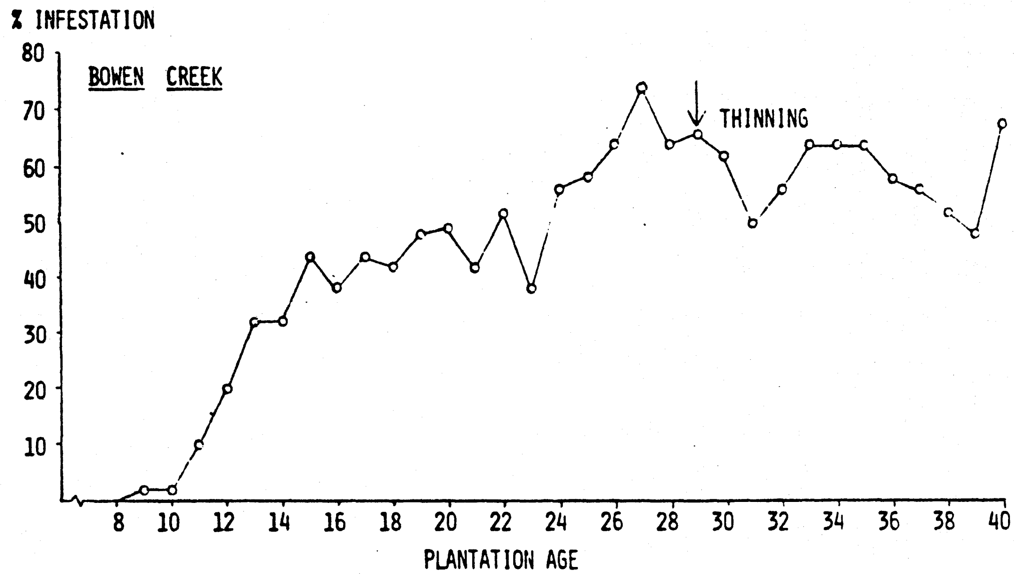


FIGURE 2. TERMINALS INFESTED WITH EUCOSMA BY PLANTATION AGE.



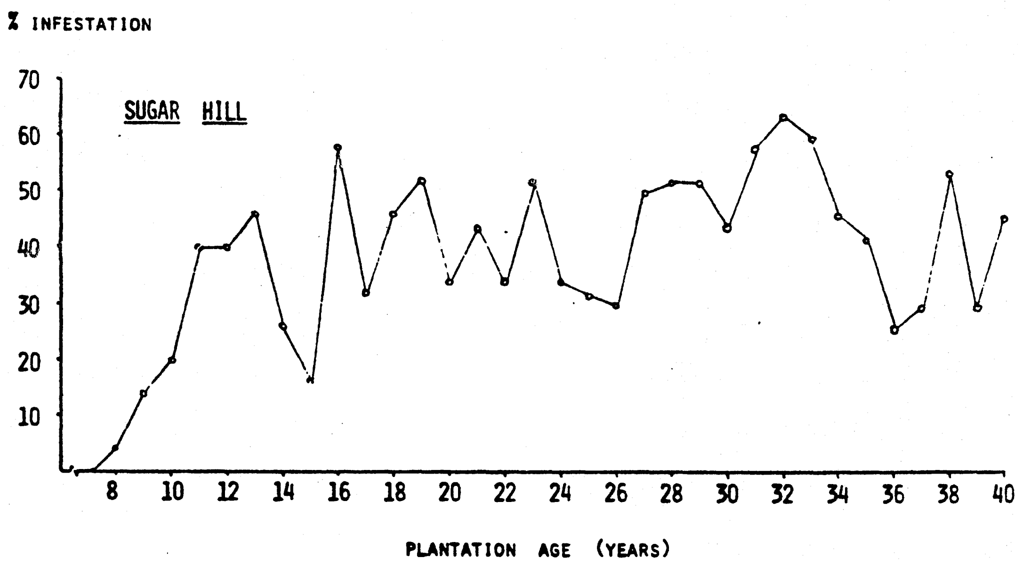
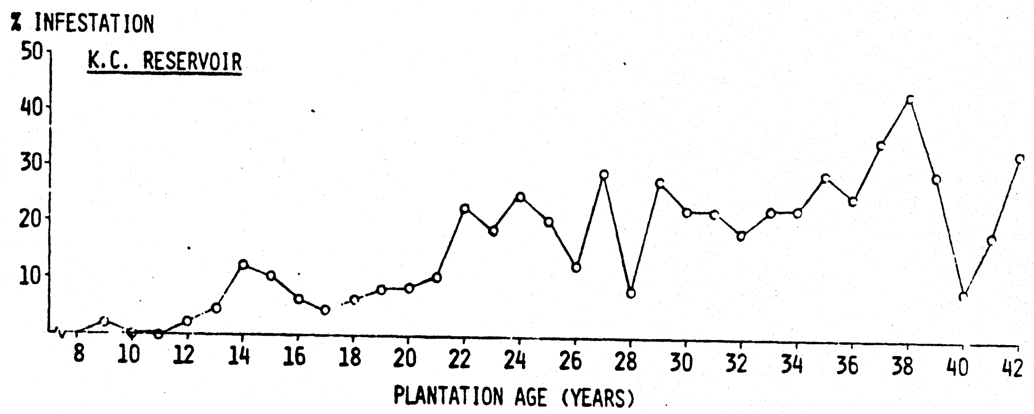


FIGURE 2. TERMINALS INFESTED WITH EUCOSMA BY PLANTATION AGE.



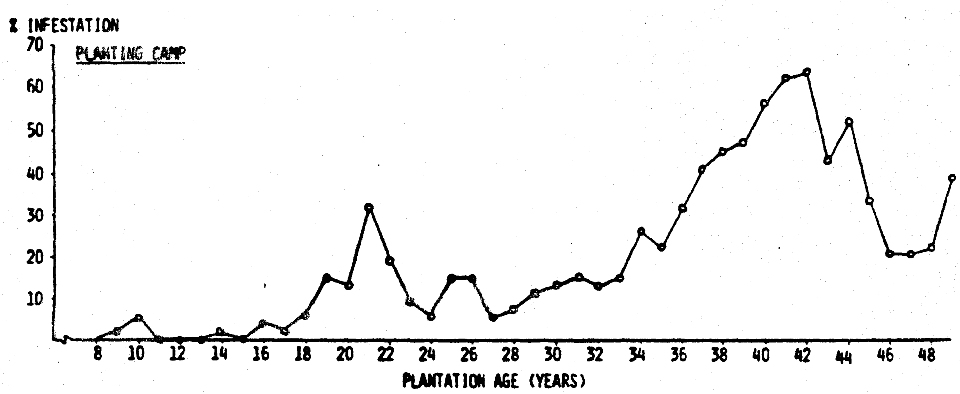


FIGURE 3. PERCENT INFESTATION AS A FUNCTION OF TOTAL TREE HEIGHT [% INF. = b_0 + b_1 (TOTAL HEIGHT)] FOR THREE TIME PERIODS AND TOTAL AGE.

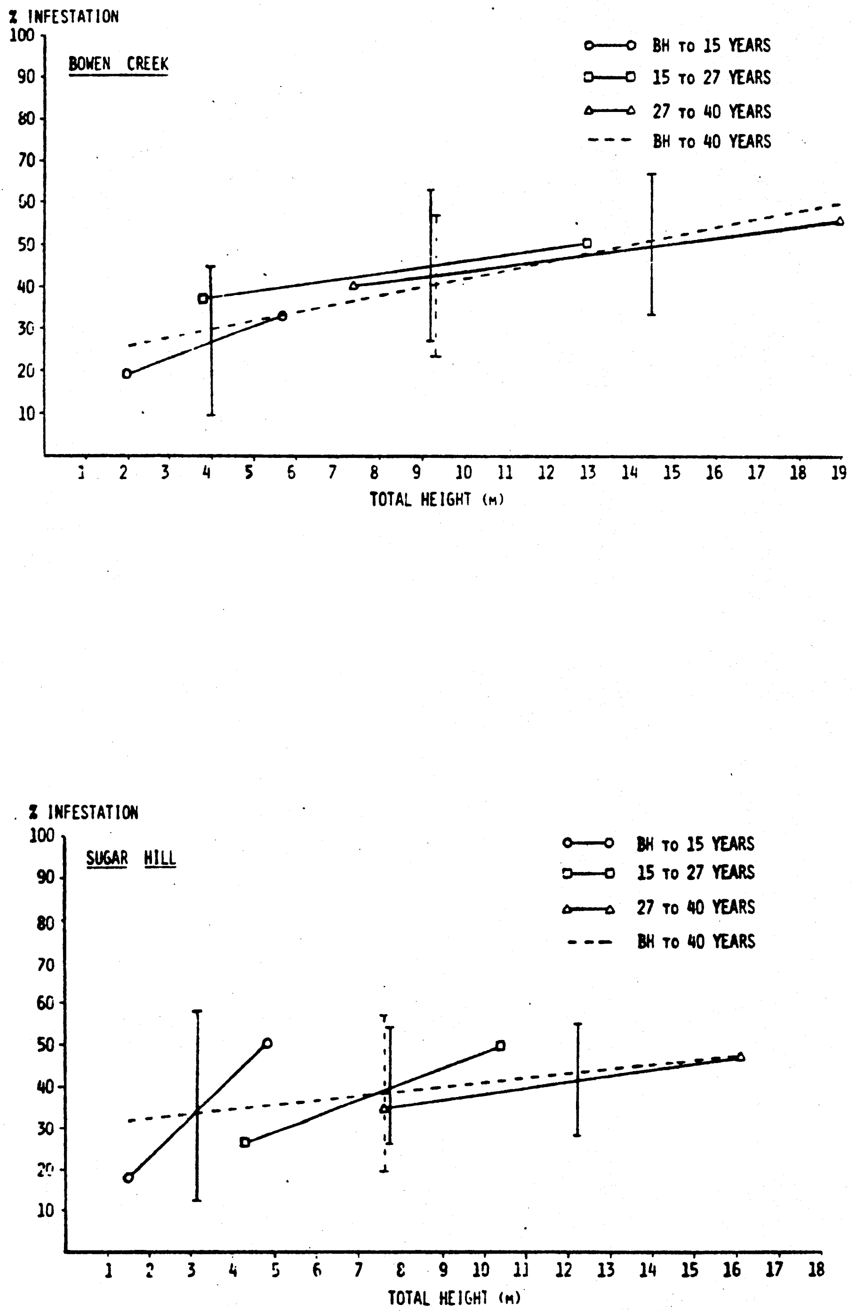
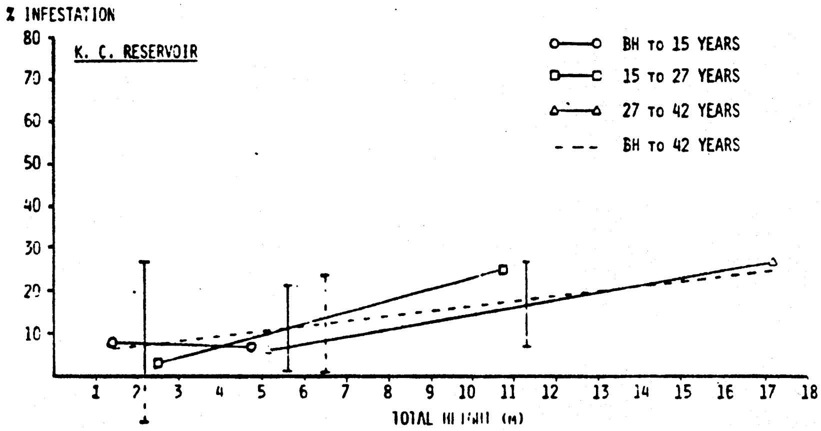


FIGURE 3. CONT. PERCENT INFESTATION AS A FUNCTION OF TOTAL TREE HEIGHT [% INF. = $b_0 + b_1$ (TOTAL HEIGHT)] FOR THREE TIME PERIODS AND TOTAL AGE.



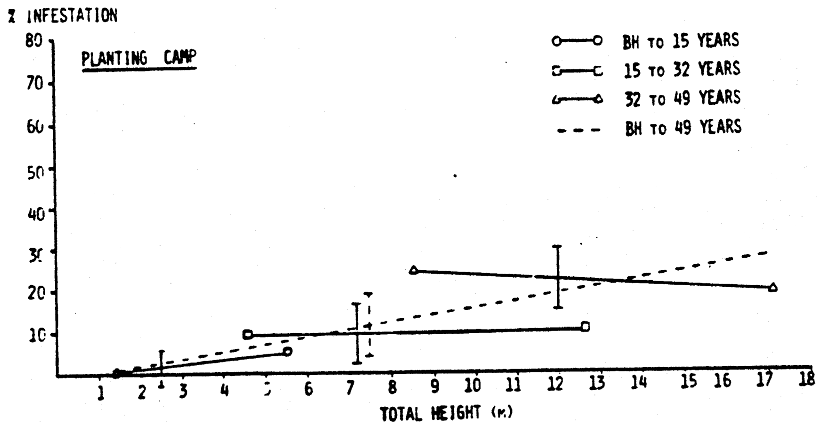


FIGURE 4. AVERAGE ANNUAL HEIGHT GROWTH BY CROWN CLASS AND INFESTATION STATUS

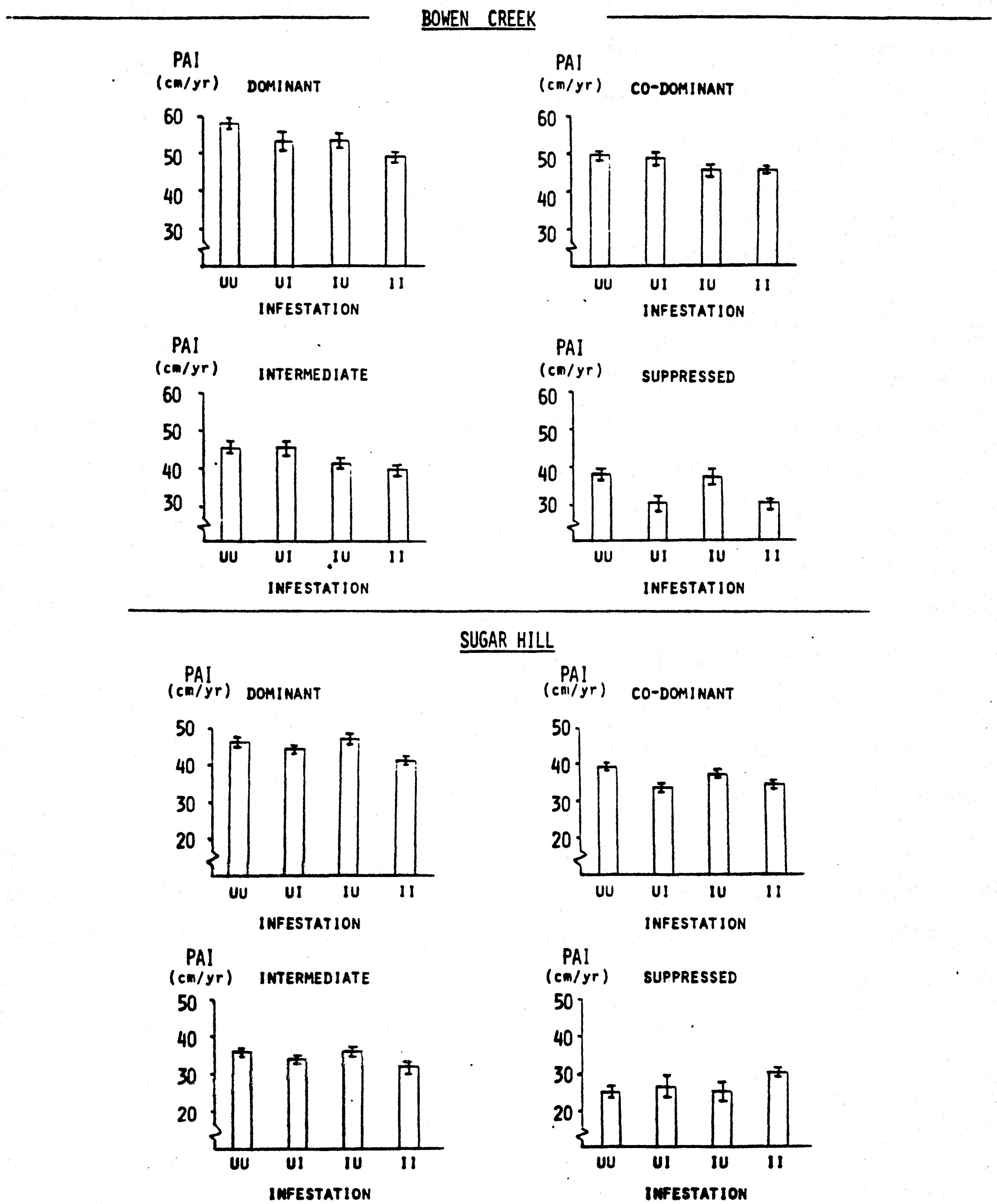
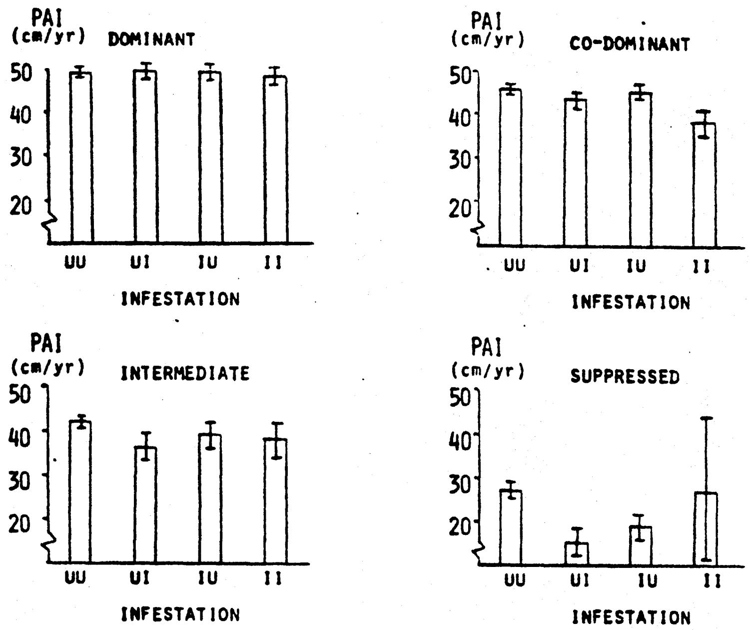


FIGURE 4 CONT. AVERAGE ANNUAL HEIGHT GROWTH BY CROWN CLASS AND INFESTATION STATUS

K. C. RESERVOIR



PLANTING CAMP

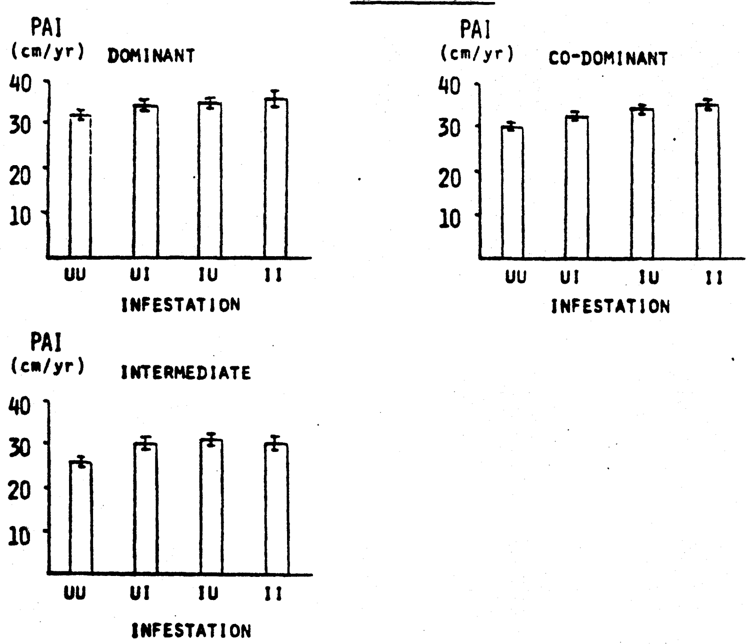


FIGURE 5. AVERAGE ANNUAL HEIGHT GROWTH (CM/YR) WITH STANDARD DEVIATIONS BY PLANTATION AND INFESTATION STATUS

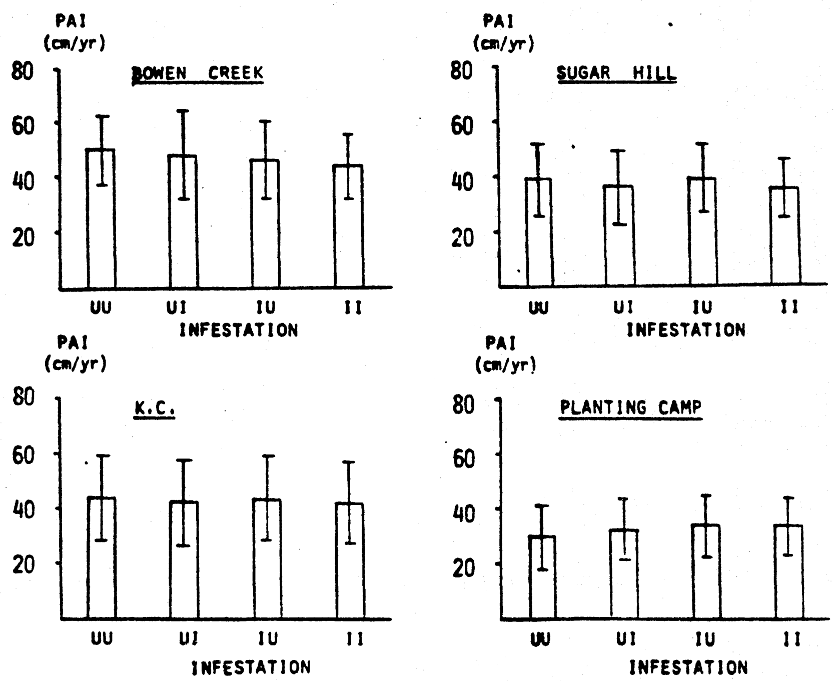


FIGURE 6A. DERIVATION OF HYPOTHETICAL UNINFESTED TREE USING THE NON-LINEAR REGRESSION TECHNIQUE PLOTTING CHANGE IN HEIGHT OVER TOTAL HEIGHT.

BOWEN CREEK - TREE 2 - DOMINANT - 42% INFESTATION

o UNINFESTED • INFESTED

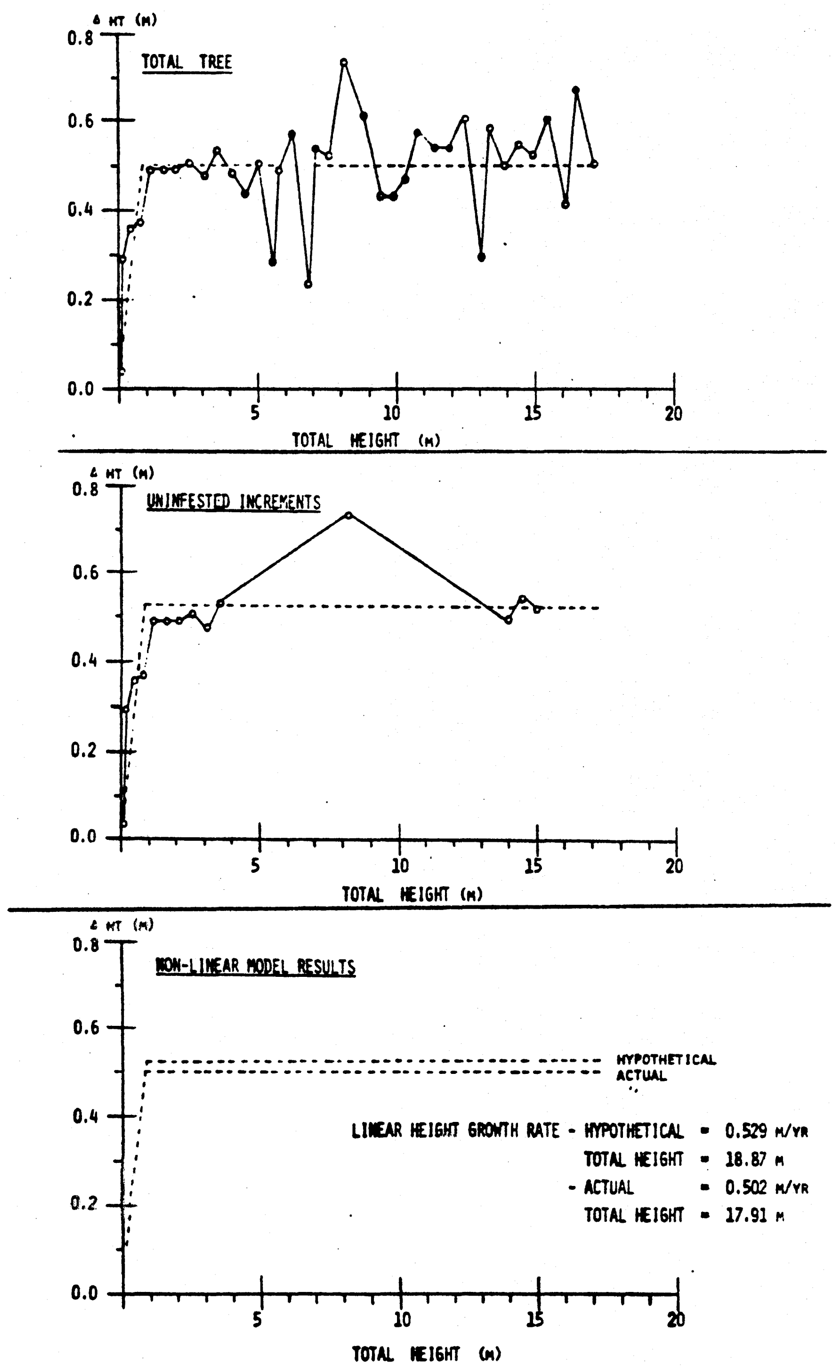


FIGURE 6B. DERIVATION OF HYPOTHETICAL UNINFESTED TREE USING NON-LINEAR REGRESSION TECHNIQUE PLOTTING CHANGE IN HEIGHT OVER TOTAL HEIGHT.

BOWEN CREEK - TREE 14 - CODOMINANT - 39% INFESTATION

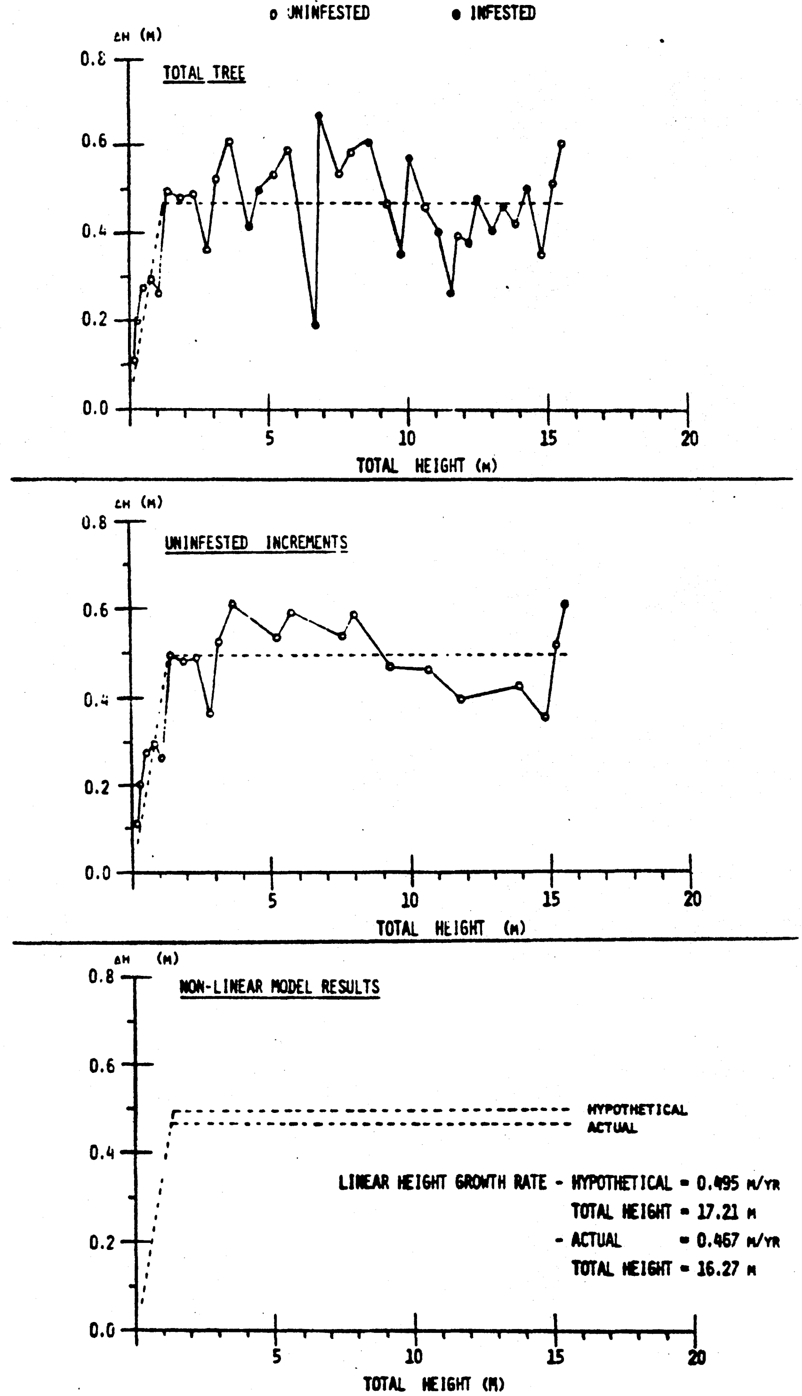
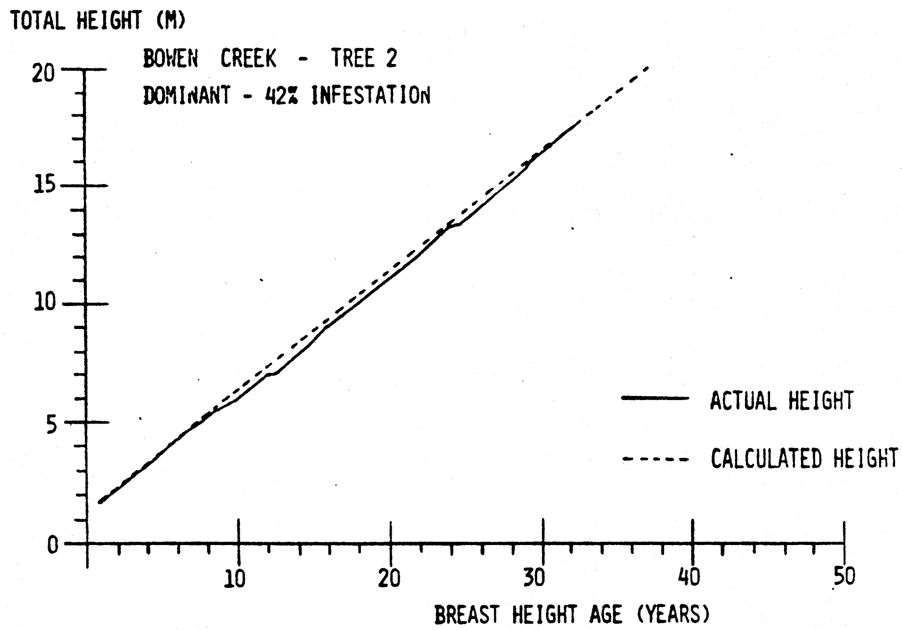
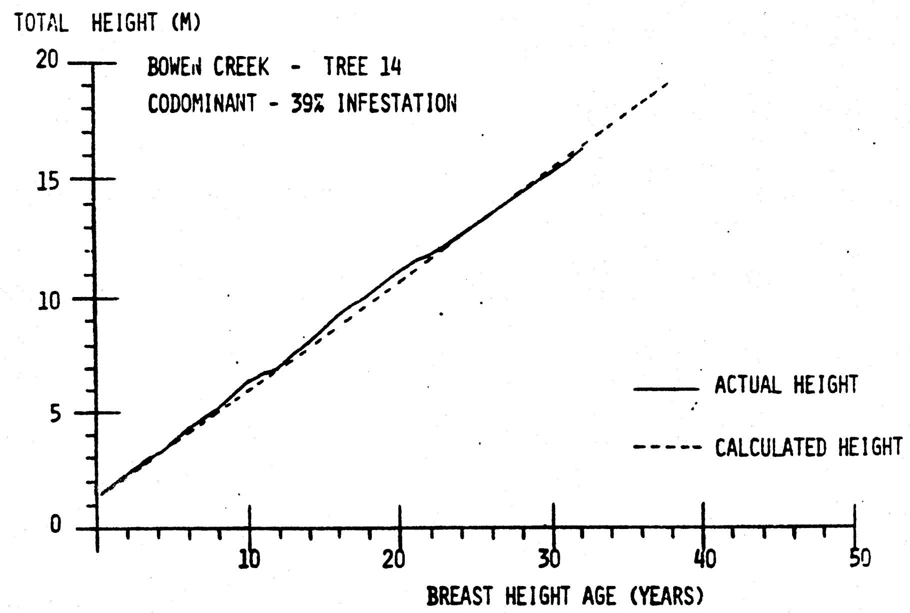


FIGURE 7. HEIGHT OVER AGE CURVES USING NON-LINEAR REGRESSION COEFFICIENTS PLOTTED AGAINST ACTUAL HEIGHT.





Appendix Table 1. Regression statistics for percent infestation as a function of plantation age (% Inf = b_0+b_1 [plantation age]) from Figure 2.

Plantation	Starting Plantation Age yrs	n	r^2	Intercept b_0	Slope b_1	Std. Error Estimate	F Statistic
Bowen Creek	9	32	0.6176	9.5647	1.5471	11.61	48.46**
	15 1/	26	0.3406	33.8479	0.7566	8.22	12.40**
Sugar Hill	8	33	0.1886	24.2193	0.6424	13.09	7.20*
	18 1/	23	0.0007	43.5988	0.0138	11.16	0.00
K.C. Reservoir	9	34	0.5937	- 4.7108	0.7707	6.45	46.75**
	20 1/	23	0.2135	3.3567	0.6164	8.21	5.70*
Planting Camp	9	41	0.5821	-13.2388	1.1788	12.12	54.32**
	19 1/	31	0.3752	-12.5439	1.1639	13.89	17.42**

1/ Starting plantation age when mean height equals 3.6 m.

* Significant at 0.05 level.
** Significant at 0.01 level.

Appendix Table 2. Regression statistics for percent infestation as a function of total height ($\%$ Inf. = $b_o + b_1$ [total height]), from Figure 3.

Plantation	Age Range	Height Range	Mean Infestation	r^2	Intercept	Slope	Std. Error Estimate	F Statistic
	yrs	m	%		b_o	b_1		
Bowen Creek	BH to 15	1.1 - 6.1	27	0.0536	11.7511	3.8023	18.17	2.55
	16 to 27	3.7 - 13.6	44	0.0274	31.6629	1.3952	18.61	1.35
	28 to 40	7.2 - 19.0	49	0.0286	33.3204	1.0700	16.66	1.41
	BH to 40	1.1 - 19.0	40	0.2124	22.1506	1.9485	17.98	39.11*
Sugar Hill	BH to 15	1.4 - 4.9	34	0.1026	3.7323	9.7084	23.19	5.48*
	16 to 27	4.3 - 10.4	40	0.1253	9.9937	3.8267	14.42	6.88*
	28 to 40	7.6 - 16.1	41	0.0464	23.1267	1.4881	13.40	2.34
	BH to 40	1.4 - 16.1	38	0.0534	30.2477	1.0619	17.97	8.35*
K.C. Reservoir	BH to 15	1.3 - 4.7	8	0.0023	8.8506	-0.3857	19.55	0.01
	16 to 27	2.4 - 10.7	12	0.2056	-2.9191	2.5784	10.34	12.42*
	28 to 42	5.1 - 17.2	17	0.2310	-3.0532	1.7404	9.59	14.42*
	BH to 42	1.3 to 17.2	12	0.1214	4.5866	1.1768	13.76	20.03*
Planting Camp	BH to 15	1.4 - 5.5	2	0.0438	-1.2768	1.1641	4.97	2.34
	16 to 32	4.6 - 12.6	10	0.0001	9.2302	0.0517	7.40	0.01
	33 to 49	8.5 - 17.1	22	0.0341	32.2678	-0.8057	7.54	1.80
	BH to 49	1.4 - 17.1	11	0.5248	-2.0299	1.7573	7.41	173.38*

* Significant at 0.05 level.

Appendix Table 3. Average annual height growth by plantation, crown class and infestation categories.

Plantation	Crown Class	UU[1/]	(SE)	UI	(SE)	IU	(SE)	II	(SE)
		Annual Height Growth (linear growth phase)							
		cm/yr							
Bowen Creek	Dom.	58.0	(1.7)	53.4	(2.2)	52.9	(1.7)	49.1	(1.2)
	Codom.	49.3	(1.0)	47.9	(1.8)	45.0	(1.3)	45.0	(0.7)
	Int.	45.4	(1.3)	45.0	(2.2)	41.0	(1.3)	38.6	(1.3)
	Sup.	37.6	(1.4)	29.8	(2.0)	36.9	(2.2)	29.8	(1.3)
Sugar Hill	Dom.	45.9	(1.0)	44.1	(1.1)	47.0	(1.1)	41.2	(1.0)
	Codom.	39.1	(0.8)	32.6	(1.1)	36.9	(0.8)	34.0	(0.8)
	Int.	35.7	(1.0)	34.0	(1.1)	35.7	(1.2)	31.8	(1.4)
	Sup.	24.9	(1.2)	26.6	(3.0)	24.9	(2.4)	30.0	(1.0)
K.C.	Dom.	49.0	(1.0)	49.3	(1.8)	49.0	(1.8)	47.9	(2.2)
	Codom.	45.6	(1.2)	43.1	(2.2)	45.5	(1.7)	38.4	(3.0)
	Int.	42.4	(1.2)	35.8	(2.9)	39.5	(3.0)	37.6	(3.8)
	Sup.	26.8	(1.8)	15.4	(3.3)	19.4	(3.0)	27.5	(12.5)
Planting Camp	Dom.	32.3	(0.7)	34.0	(1.2)	35.2	(1.1)	35.6	(2.0)
	Codom.	30.1	(0.5)	32.3	(1.1)	34.2	(1.2)	34.9	(1.0)
	Int.	26.0	(0.6)	30.2	(1.6)	30.9	(1.4)	30.3	(1.5)

[1/] UU = uninfested from previously uninfested leader.
UI = uninfested from previously infested leader.
IU = infested from previously uninfested leader.
II = infested from previously infested leader.

Appendix Table 4. Residuals for actual versus estimated total heights using change in height over total height model.

Plantation	Crown Class	Mean Residuals[1/]	Std. Error
		cm	cm
Bowen Creek	Dom.	+19	7
	Codom.	+14	10
	Int.	+ 7	4
	Sup.	+ 7	3
Sugar Hill	Dom.	+ 4	2
	Codom.	+ 2	2
	Int.	+ 4	2
	Sup.	+ 8	-
K.C.	Dom.	+ 6	5
	Codom.	+ 3	3
	Int.	- 1	3
	Sup.	- 1	3
Planting Camp	Dom.	+ 2	2
	Codom.	+ 1	2
	Int.	+ 5	3
All Plantations	Dom.	+ 7	1
	Codom.	+ 5	1
	Int.	+ 4	1
	Sup.	+ 3	1

[1/] Mean residuals = sum (estimated height minus actual height) divided by n